CONTROL APPARATUS FOR VIBRATION TYPE ACTUATOR

BACKGROUND OF THE INVENTION

Field of the Invention

5   The present invention relates to a control

apparatus for a vibration type actuator such as a

vibration wave motor or the like.

Related Background Art

Generally, a vibration type actuator such as a

10   vibration wave motor or the like includes a vibration

member for making driving vibration and a contact

member for coming into contact with the vibration

member in pressurization, and causes the vibration

member and the contact member to relatively move by the

15   driving vibration.

Then, the vibration member generally consists of

an elastic member and a piezoelectric element

functioning as an electro-mechanical energy conversion

element. For example, the piezoelectric element is

20   disposed so as to have the driving phase at the

position having spatially a mutual phase difference of

90° for the driving phase of the elastic member,

alternating signals of two phases having a mutual phase

difference of 90° are applied to these two driving

25   phases to generate a travelling wave on the elastic

member, and the contact member is pressure-contacted

with the elastic member, thereby obtaining driving force

frictionally.

Here, it should be noted that a frictional material for obtaining the appropriate frictional force is adhered, coated or formed at the contact portion between the vibration member and the contact member.

With respect to the features of the vibration type actuator, as compared with an actuator using electromagnetic force, several points that driving torque at low speed is large, responsiveness is excellent, and it is silent because, as the vibration over an audible range is used, humans can not feel any driving sound are enumerated. Therefore, the vibration type actuator is suitably used as, e.g., the driving unit of an image formation apparatus.

Generally, since a large voltage is necessary for the vibration type actuator, the voltage is boosted or risen by one method or a combination of plural methods. For example, a driving signal is amplified by a linear amplifier, the voltage is boosted by a transformer, or an inductance element and a switching element are combined and thus a resonance with the capacitance component of the vibration type actuator is used.

In these methods described above, the method of boosting the voltage by the transformer or the method of boosting the voltage by combining the inductance element and the switching element is desirably used because it is excellent in respects of efficiency,

costs and the like.

Moreover, as methods of controlling the driving speed of the vibration type actuator, there are a method of controlling the driving speed by using a driving voltage, a method of controlling the driving speed by using a driving frequency and a method of controlling the driving speed by using a phase between adjacent driving phases. In these methods, the method of controlling the driving speed by using the driving frequency is desirably used because it can achieve both a wide dynamic range and high resolution singly and is excellent in conformity with a recently developed digital circuit.

However, in the driving speed control method using the driving frequency, as shown in Fig. 4, a frequency-speed characteristic changes greatly according to a frequency, whereby there is a problem that a change rate of the speed varies even at the same control operation amount.

Particularly, if the frequency is apart from a resonance frequency (fr), a tilt (i.e., the tilt of the frequency for the speed) decreases, whereby there is a problem that a necessary control gain can not be obtained and the speed does not decrease.

That is, there is a problem that controllability deteriorates in a low-speed range. Besides, if the control gain is set at low speed, there is a problem

that oscillation occurs in high-speed driving.
Particularly, when the vibration type actuator is used
in positioning control, there is a problem that a
desired device can not be accurately stopped at a

5   desired position.

SUMMARY OF THE INVENTION

An object of the invention is to provide a control
apparatus, for a vibration type actuator, which

10   achieves steady driving by a simple manner in a wide
range of the driving from high speed to low speed.

One aspect of the invention is to provide a
control apparatus for a vibration type actuator, which
makes driving vibration at a driving unit of a

15   vibration member by applying an alternating signal to
an electro-mechanical energy conversion element and
uses at least a frequency of the alternating signal as
a speed control parameter, the apparatus comprising:

a driving circuit capable of changing a driving

20   voltage of the alternating signal to be applied to the
electro-mechanical energy conversion element; and a
control circuit for controlling the driving circuit so
that at least an absolute value of a tilt of a
frequency-speed characteristic of the actuator is

25   within a predetermined range in a frequency band of
predetermined range.

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a speed control parameter, the apparatus comprising:

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voltage of the alternating signal to be applied to the
electro-mechanical energy conversion element; and a
10   control circuit for controlling the driving circuit so
that an absolute value of a tilt of a frequency-speed
characteristic of the actuator is a predetermined value
or more at least in a frequency band of predetermined
range.

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control apparatus for a vibration type actuator, which
makes driving vibration at a driving unit of a
vibration member by applying an alternating signal to
an electro-mechanical energy conversion element and
20   controls at least a frequency of an alternating signal
as a speed control parameter, the apparatus comprising:

a driving circuit capable of changing a driving
voltage of the alternating signal to be applied to the
electro-mechanical energy conversion element; and a
25   control circuit for at least performing control in a
frequency range higher than a predetermined frequency
so that the driving voltage to be applied to the

electro-mechanical energy conversion element by the driving circuit decreases as the predetermined frequency becomes a higher frequency.

Other objects of the invention will become
5   apparent from the following embodiments which will be explained with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing the first
10   embodiment of the invention;

Fig. 2 is a cross-sectional view showing the structure of an example of a vibration type actuator in the invention;

Fig. 3 is a block diagram showing a conventional
15   control apparatus corresponding to the invention;

Fig. 4 is a view showing a frequency-speed characteristic of the vibration type actuator in the invention;

Fig. 5 is a view showing an example of a speed
20   command in position control;

Fig. 6 is a view showing the frequency-speed characteristics of the vibration type actuator, in the first embodiment of the invention and a conventional control circuit;

25   Fig. 7 is a view showing the frequency-speed characteristics of the vibration type actuator, in the modification of the first embodiment and the

conventional control circuit;

Fig. 8 is a block diagram showing the second embodiment of the invention;

Fig. 9 is a block diagram showing the third embodiment of the invention;

Fig. 10 is a block diagram showing the fourth embodiment of the invention;

Fig. 11 is a view showing pulses for driving a MOSFET in a conventional example;

Fig. 12 is a view showing a state that pulses for driving a MOSFET are squeezed in the invention;

Fig. 13 is a view showing the frequency-speed characteristic of the vibration type actuator in the first embodiment of the invention;

Fig. 14 is a block diagram showing the fifth embodiment of the invention; and

Fig. 15 is a view showing an operation in the fifth embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS
(First Embodiment)

Fig. 1 is a block diagram showing the first embodiment of the invention, Fig. 2 is a cross-sectional view showing an example of a vibration type actuator which can effectively perform the invention, and Fig. 3 is a block diagram showing a conventional positioning circuit corresponding to the circuit shown

in Fig. 1.

In the vibration type actuator shown in Fig. 2, both sides of a laminated piezoelectric element 17 which has plural sets of two driving phases disposed at positions having spatially a mutual phase difference of 90° are put and supported between elastic members 16 and 18. By applying alternating signals of two phases having a mutual phase difference of 90° to the two driving phases of the piezoelectric element 17, travelling waves as driving vibrations are generated on the outer surfaces of the respective elastic members 16 and 18, and rotation members 15 and 19 functioning as contact members are pressure-contacted with the elastic members 16 and 18 respectively, thereby obtaining driving force based on frictional force. Here, for example, plural ranges respectively having different polarization directions are provided in each driving phase. Thus, for one driving phase, displacements of expansion and shrinking are simultaneously given in the thickness direction (axial direction) by applying the sine-wave alternating signals to the ranges of the different polarization directions, whereby bending vibration is made. Similarly, for the other driving phase, the bending vibration is made by applying the cosine-wave alternating signals. Moreover, in a case where the polarization ranges of the respective driving phases are turned to the same polarization direction,

the phase-inverted alternating signals are applied.

When the actuator is driven, pulses having arbitrary pulse widths and frequencies and having a mutual phase difference of 180° are applied to the gates of MOSFET's (metal oxide semiconductor field-effect transistors) 7 and 8 for the one driving phase connected to a coil 11 and to the gates of MOSFET's 9 and 10 for the other driving phase connected to a coil 12.

That is, the switching pulse is set to have the phases 0°, 180°, 90° and 270° in due order from g1 to g4 with the pulse width of approximately 50%, as shown in Fig. 11. When the pulse is inverted, it is set to have the phases 0°, 180°, -90° and -270° in due order from g1 to g4. The value of the coil is set to match the capacitance of the vibration type actuator. Actually, the resonance frequencies of the coil and the capacitance are set to be higher than the resonance frequency of the actuator to moderate a change rate of a voltage.

Fig. 3 shows an example of the conventional positioning control circuit. In the control circuit of a conventional vibration type actuator 13, a speed signal v of a speed detection means 14 such as a known rotary encoder or the like for detecting the rotation of the vibration type actuator 13 is converted into a position signal P by a position counter 5. Then, a

speed command Vc according to the current position is generated by a position control block 2 to reach the target position, e.g., as shown in Fig. 5. Further, a frequency f of the pulse to drive the vibration type actuator is determined based on the speed command Vc, the speed signal V from the speed detection means 14, a control gain and the like by a speed control block 3, and the determined frequency f is output to a pulse generator 6.

A pulse width PW of a pulse generated by the pulse generator 6 is set to have a predetermined value irrespective of the command frequency f.

The pulses of four phases are generated based on the command frequency f and the pulse width PW by the pulse generator 6 to drive MOSFET's 7 to 10, whereby the vibration type actuator 13 is driven through coils 11 and 12.

Since the vibration type actuator 13 has the frequency-speed characteristic (i.e., the speed characteristic for the change in a unit amount of the frequency) as shown in Fig. 4, the speed can be controlled by adjusting the frequency. However, since the tilt of the frequency-speed characteristic changes greatly according to the frequency, there is a fear that satisfactory control can not be performed according to the speed range. Particularly, the gain does not suffice in low speed. In the positioning

control, to improve the stop accuracy and decrease an impulsive sound at the time of start and stop, the speed control as shown in Fig. 5 is performed. In this case, it is necessary to perform the steady speed

5   control within a wide speed range. Particularly, the stability in the low-speed range is important. Moreover, since the speed does not decrease enough in a predetermined frequency range, there is a fear that it causes an overrun.

10   On the other hand, in the first embodiment of the invention, as shown in Fig. 1, a pulse width PW corresponding to a frequency command f generated by a speed control block 3 is stored beforehand in a known memory device 4 such as a RAM, a ROM or a gate array,

15   and thus the pulse width PW according to the frequency command f is output to a pulse generator 6.

A table for the frequency commands f and the pulse widths PW is set beforehand by experiment or study so that the absolute value of the tilt of the frequency-

20   speed characteristic can secure a gain enough for the control or can be set in a predetermined range. Fig. 6 shows the frequency-speed characteristics in the conventional art and the first embodiment.

In the first embodiment, the pulse width for the

25   frequency is determined so that the frequency-speed characteristic almost becomes a straight line. That is, the pulse width is maximum at a point a (frequency

fa), and the pulse width is squeezed at the above and below of the point a (above and below of frequency fa). Fig. 12 shows the state that the pulses are squeezed with the frequency same as that in Fig. 11. As a

5   result, since the response to the control command becomes the same at any frequency, the steady control can be performed in the wide speed range from high speed to low speed, whereby it is suitable for the positioning control.

10   Incidentally, it is difficult to make the frequency-speed characteristic linear accurately and completely. However, as shown in Fig. 13, there is no problem even if a range of the tilt of the frequency-speed characteristic is determined and the tilt is made

15   to be put within this range.   :

Besides, if the necessary gain only has to be secured, it is also effective to set the absolute value of the tilt of the frequency-speed characteristic of the vibration type actuator to be a predetermined value

20   or more as shown in Fig. 7. In this case, the pulse width is squeezed at the frequency above a point a (frequency fa). Although the frequency-speed characteristic does not become linear entirely in the used frequency range, the control can be performed in

25   the wide speed range because the necessary control gain can be secured. In this case, the control becomes possible even as for higher speed farther. Although

the apparatus for positioning control was explained in the first embodiment, the same effect as above can be obtained if the embodiment is applied to an apparatus only for speed control.

5   (Second Embodiment)

Fig. 8 shows the second embodiment of the invention.

It should be noted that, in the second embodiment, the explanation of the same parts as those in the first

10   embodiment will be omitted. According to the second embodiment, in a speed control block 3 which consists of a logic circuit such as a known CPU, a gate array or the like, a reduction number $\Delta PW(f)$ of the pulse width is calculated from a command frequency f, and thus a

15   command pulse width PW is determined.

For example, the reduction number of the pulse width can be calculated from the frequency fa at the point a of Fig. 6 and the command frequency f by using an equation $\Delta PW(f) = k|f-fa|$. Here, the value of k

20   which is a constant is set so that the tilt of the frequency-speed characteristic of the vibration type actuator is put within an almost-constant predetermined range. In the second embodiment, any memory element is not necessary, and its substitute can be achieved by

25   using the element shared with another block such as the CPU or the gate array.

Incidentally, if the pulse width is decreased only

in case of f > fa, the same effect as that shown in Fig. 7 of the first embodiment can be obtained, whereby the control becomes possible as for higher speed.

Although the apparatus for positioning control was
5 explained in the second embodiment, the same effect as above can be obtained if the embodiment is applied to an apparatus only for speed control.

(Third Embodiment)

Fig. 9 shows the third embodiment of the
10 invention. It should be noted that, in the third embodiment, the explanation of the same parts as those in the first embodiment will be omitted.

According to the third embodiment, a DC power supply 1 is a controllable power supply which can
15 control a voltage by a digital signal, a voltage and other means. A memory device 4, which stores a table for a frequency and a voltage value command DCV of the DC power supply, outputs the command voltage DCV to the DC poser supply 1 in accordance with a command
20 frequency f output from a speed control block 3.

As well as the first and second embodiments, to be able to secure the gain enough for the control, the third embodiment is set so that the absolute value of the tilt of the frequency-speed characteristic of the
25 vibration type actuator is put within a predetermined range.

That is, the voltage of the DC power supply is

decreased at the upper and lower portions of the driving frequency range (high-frequency portion and low-frequency portion within the frequency range used for driving). Therefore, the amplitude in the part

5   where the voltage of the DC power supply was decreased becomes small, whereby speed decreases. The effect obtained by doing so is the same as the effect in the first embodiment.

Further, if it is to only secure the necessary

10   gain, the voltage of the DC power supply may be decreased at a predetermined frequency, higher than the resonance frequency of the vibration type actuator, or more. Moreover, as well as the second embodiment, a reduction rate of the voltage of the DC power supply to

15   the frequency may be calculated by the speed control block.

(Fourth Embodiment)

Fig. 10 shows the fourth embodiment of the invention. It should be noted that, in the fourth

20   embodiment, the explanation of the same parts as those in the first embodiment will be omitted. In Fig. 10, numeral 15 denotes an oscillator which performs oscillation at a frequency according to a frequency command f output from a speed control block 3 such as a

25   known VCO (voltage-controlled oscillator). Numeral 16 denotes a power amplifier to which a gain command Ga can be set externally. A memory device 4, which stores

a table for a frequency and the gain command Ga of the power amplifier 16, outputs the gain command Ga of the power amplifier 16 in accordance with the frequency command f output by the speed control block 3. As well

5   as the first and second embodiments, to be able to secure the gain enough for the control, the fourth embodiment is arranged so that the absolute value of the tilt of the frequency-speed characteristic of the vibration type actuator is put within a predetermined

10   range.

That is, the gain of the power amplifier 16 is decreased at the upper and lower portions of the driving frequency range. The effect obtained by doing so is the same as the effect in the first embodiment.

15.   Further, if it is to only secure the necessary gain, the gain of the power amplifier 16 may be decreased at a predetermined frequency, higher than the resonance frequency of the vibration type actuator, or more. Moreover, as well as the second embodiment, a

20   reduction rate of the gain of the power amplifier 16 to the frequency may be calculated by the speed control block.

(Fifth Embodiment)

Fig. 14 is a block diagram showing the fifth

25   embodiment of the invention. Here, a timer 24 generates a trigger signal Tg at a constant interval, and an up down counter 25 performs up and down count in

accordance with the trigger signal Tg from the timer
24. Further, a position control block 2 generates a
speed command Vc as shown in Fig. 5 and also generates
a control state signal SM.

5   The operation of the up down counter 25 is
determined by the value of the control state signal SM.
As shown in Fig. 15, at the time of acceleration (SM =
1), the pulse width increases from the initial pulse
width whenever the trigger signal Tg is input, while at
10   the time of deceleration (SM = 3, 4), the pulse width
decreases whenever the trigger signal Tg is input.
Since the frequency-speed characteristic of the
vibration type actuator is as shown in Fig. 4, the
driving frequency decreases most at constant speed,
15   and, on the other hand, the driving frequency increases
at the time of acceleration and deceleration. At this
time, a period that the timer generates the trigger
signal Tg and amounts of increase and decrease of the
pulse width are appropriately set so that the
20   frequency-speed characteristic of the vibration type
actuator has the curve same as the curve shown in Fig.
7. The changes of the frequency and the pulse width at
this time are shown in Fig. 15. Also in this case,
since the frequency-speed characteristic is corrected
25   to become nearly linear, as well as the first to fourth
embodiments, controllability in each speed range
becomes steady.

Here, both the cases of acceleration and deceleration were explained, the above operation may be performed only at the time of deceleration (SM = 3, 4) which is most important for positioning accuracy.

5   Further, it is also effective to perform the above operation only when SM = 3 in some deceleration to prevent the stop unanticipated at low speed, and to set a limit value PWmin for the pulse width as shown in Fig. 15 so that the pulse generator does not output the

10   pulse width below the limit value.

In the above description, although the pulse width was explained as a parameter to correct the frequency-speed characteristic of the vibration type actuator, of course, it is also effective to directly modify the

15   applied voltage, the voltage of the DC power supply, the gain of the linear amplifier or the like at a constant period.